NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1378

Abundance of Microflora in Soils of Desert Regions

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Preface

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Abstract

Surface soils were collected by aseptic techniques from cold, polar, hot, volcanic, and high mountain deserts, and were analyzed for physical, chemical, and microbiological properties. Soils showed a wide range of properties but were generally greyish, yellowish, or brownish sands, low in organic matter and cation exchange capacity. There were detectable concentrations of water-soluble ions, and pH values above 7.0, except in volcanic areas. Total microbial abundances ranged from zero (undetectable) to $> 10^8$/gm of soil. Aerobic and microaerophilic bacteria were most abundant, followed by algae and molds. The anaerobic bacteria were generally least abundant or undetectable. Predominant microflora included *Bacillus* spp., soil diphtheroids, *Schizothrix* spp. and other oscillatorioid blue-green algae, *Streptomyces* spp., *Penicillium* spp., and *Aspergillus* spp.

Abundance of Microflora in Soils of Desert Regions

I. Introduction

In preparation for investigation and detection of life in extraterrestrial environments, especially Mars, terrestrial desert soils are being collected and analyzed to determine their physical, chemical, and microbiological properties (Refs. 1–7).

Desert soils have served as test materials for possible extraterrestrial life detection experiments and have provided background information relevant to desert soil microbial ecology, especially in the harshest desert areas. Studies of desert soil microbial ecology are necessary because environmental factors are so restrictive outside of our own planet, that higher life forms are not expected to exist anywhere else in our solar system. However, if moisture is available, especially in thermal, salt, permafrost or other favorable "microenvironments," then it is possible that microorganisms may be present.

Investigations on the nature of the terrestrial soil environment, and the abundances and kinds of microorganisms in a wide variety of desert habitats are not only useful to extraterrestrial life detection programs (Ref. 8), but also provide comparative information on a variety of arid lands. These arid lands are becoming increasingly important since formerly nonarable desert areas are needed for habitation and food production.

Although the data presented in this report are far from complete and are only of a preliminary nature for any one desert region, it is a first attempt to bring together results obtained by similar methods of analyses on a variety of desert soils. In regard to planetary exploration, this report is a preliminary attempt to answer the question: "What kinds of soils and how many types of microorganisms could we find if our space probe should land by chance in a particular uninhabited desert area?"

Insofar as possible, samples were collected aseptically away from inhabited areas. Where no samples were available from a particular desert area (i.e., polar or high Arctic deserts), then the literature was relied upon for this source of information (Refs. 9–12). Unfortunately, as indicated in the literature, most investigations of desert soils emphasized either physical and chemical properties of the soil or some other aspect of soil science, and the microbiological properties received little or no emphasis, or vice versa.

Although the number of desert areas represented appears to be quite small and approximately one-half of the data is based on North American deserts, it should be noted that, compared with the rest of the world, western North America has the greatest concentration of different types of deserts (Ref. 13). In this regard, the North American deserts have their counterparts in the deserts of the Old World and in the Southern Hemisphere. For example, the Chihuahuan Desert has its analogues in the Karoo of South Africa; the Wyoming Red Desert resembles the Gobi; parts of the Great Basin Desert parallel the Kyzyl Kum and Kara Kum Deserts; and the Sonoran Viscaino Magdalena is climatically similar to the desert coasts of Libya and Tunis as well as the Negev of Israel and southern Atacama Desert of Chile. The Sonoran Arizona Upland Desert has climatic analogues in parts of the Kalahari Desert and parts of the interior of Australia and Patagonian Desert, and the dry Sonoran Colorado Desert approaches that of the conditions found in the central Sahara, along the coast of the Red Sea and the Great Australian Desert (Ref. 13).

No attempt has been made in this report to subdivide desert areas, except as cold, polar, hot, and specialized high mountain and volcanic deserts. For deserts other than those that are cold, polar, or specialized, reference has been made to an updated revision of Peveril Meigs's 1952 maps (Ref. 14). To conform with accepted terminology, it is generally considered that polar deserts are located in the high Arctic, and cold deserts are found in the Antarctic (Refs. 8 and 15).

II. Materials and Methods

Soils were collected from a variety of desert areas using aseptic techniques to avoid contamination of samples (Ref. 16). Environmental measurements were made at each site (Figs. 1 and 2) and pictures were taken to record the appearance of the soil structure, site, general area, and other pertinent biotic, geologic, or topographic features applicable to soil microbial ecology (Figs. 3–6). After the soils were transported to the laboratory, they were assigned code numbers, catalogued, and processed for analyses (Ref. 17). The data presented for each soil sample were from a selection of approximately 400 sets of analyses of desert soils.[1]

[1]Analyses are from the unpublished results of the JPL desert microflora program, 1961 to date.

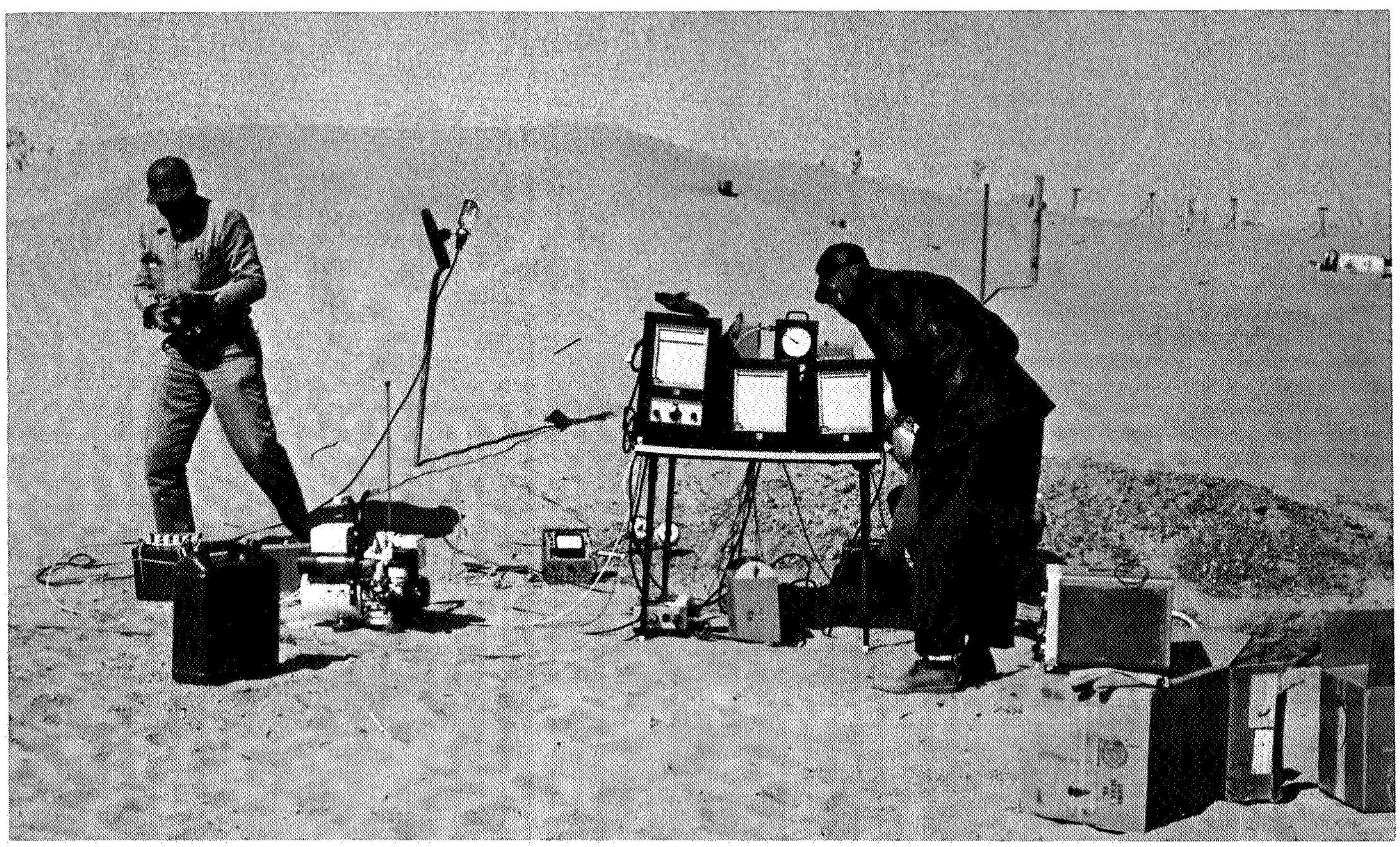

Fig. 1. Temperature, relative humidity, and wind velocity measurement in the barchan Algodones Dunes of the Sonoran Yuma Desert (JPL soil No. 88)

Fig. 2. Soil moisture and density measurement in felsenmeer of stony sandy loam, semiarid high-altitude polar environment at White Mountain Summit, Inyo National Forest, California, elevation 4,350 m (JPL soil No. 14)

Soil physical and chemical analyses were determined by standard methods, with some modifications for highly saline or acid soils containing low levels of organic matter (Refs. 18–22). Other modifications were necessary when the total quantity of sample was limited.

In general, the following methods were used to determine soil physical and chemical properties.

(1) Texture was determined by the hydrometer method.

(2) Soil color and Munsell Notation were observed on the air-dry soil by comparison with Munsell soil color charts.

(3) The *in situ* moisture content was obtained gravimetrically by drying the soil to constant weight at 105°C (±5°C).

(4) After 1-h equilibration, pH was determined on the saturated soil paste.

(5) Electrical conductivity values were obtained on the soil: water (1:5) extract; soluble cations and anions were obtained with a slightly acidified soil: water (1:5) extract followed by colorimetry, flame photometry, or atomic absorption spectrometry.

(6) Analyses for organic carbon were by chromic acid digestion and gravimetric determination of evolved CO_2.

(7) Organic nitrogen was determined by the Kjeldahl method.

(8) Cation exchange capacity was usually determined by means of the barium chloride-triethanolamine procedure.

General groups of soil microflora were determined by cultural methods for bacteria, fungi, and algae (Refs. 23–26 and 19). A combined colony count was made of aerobic bacteria and actinomycetes (streptomycetes) in trypticase soy agar, and the anaerobic bacteria were obtained on the same medium in a CO_2 chamber.

Microaerophiles were reported as bacteria (or actinomycetes) growing in fluid thioglycollate medium, which

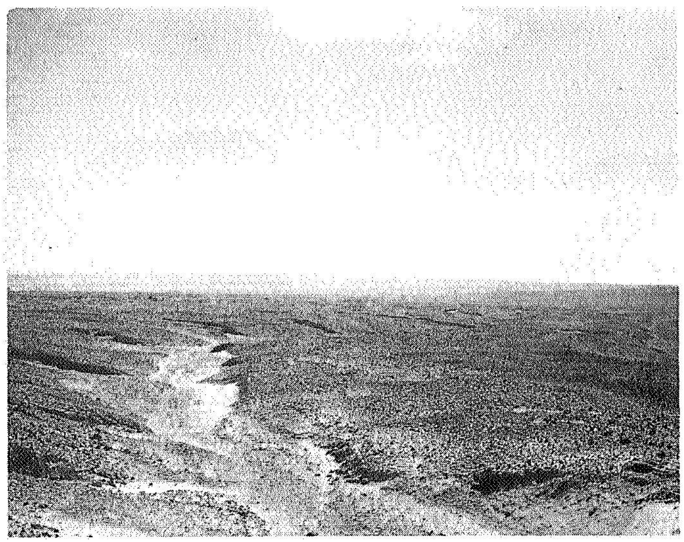

Fig. 3. Valley of 10,000 Smokes, Katmai National Monument, Alaska; a specialized, moist, barren volcanic pumice-ash desert (JPL soil No. 116)

Fig. 4. Atacama Desert, near Prosperidad, Chile; a hot, dry, barren, salt-encrusted caliche coastal desert (JPL soil No. 288)

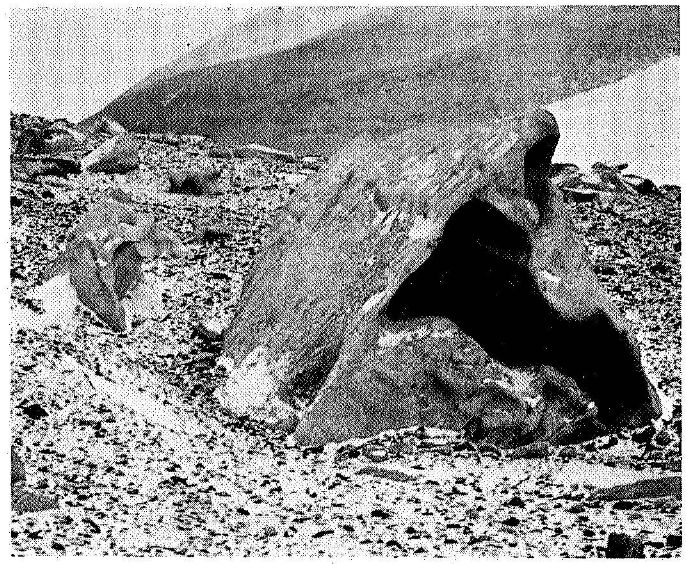

Fig. 5. The cold, barren, windswept, and ventifacted Asgard Range, Antarctica; a cold desert site devoid of microorganisms (JPL soil No. 664)

was nearly always subsurface growth in the higher dilutions. The molds were selectively isolated on Martin's or Cooke's rose bengal agar, and the yeasts were obtained with diMenna's agar. Algae were cultured in Pochon's salt solution with the addition of desert soil extract during the first few years of the JPL desert microflora program, but Thornton's salt medium without organics has been used most frequently to obtain algal growth.

Incubation temperatures, except for the algae, were usually at or slightly below "room temperature," 20–23°C, and at high humidities, >90% RH, for periods of 5 days to 6 wk. For the algae, room temperatures were usually from 23 to 27°C and frequently under continuous warm white or Sylvania Gro-lux fluorescent illumination of approximately 250 to 550 ft-cd for periods up to 6 mo.

Ten-fold serial dilutions were made of 1–10 g quantities of sieved ($\leqq$2 mm) air-dry or *in situ* moist soil. For some samples containing low abundances of microorganisms (or lacked microorganisms), 1–5 g quantities of soil were sprinkled on agar surfaces. Cold desert microbiological abundances were obtained on spread plates or in dilution tube cultures of soil at the *in situ* moisture content.

All of the microaerophilic bacteria and algae were determined in dilution tubes, and their abundances were reported for positive growth at the highest dilution.

Fig. 6. Profile of faintly developed polar desert soil on a glacio-fluvial deposit overlain by desert pavement, Inglefield Land, Greenland

Dilution tubes were checked for growth by both macroscopic and microscopic examination. Microscopy involved light, phase, or fluorescent techniques. In some cases, when the diluted soil or salts made observations difficult, transfers were made to additional media for subsequent verification of growth of microorganisms. A Quebec colony counter was used for plate counts.

III. Results and Discussion

The results of physical and chemical analyses of desert soils are presented in Table 1. It is apparent that soils from a wide variety of desert habitats have only a few properties in common. In this regard, most of them have sandy textures, brownish or greyish color, and generally oxidized as indicated by their soil colors and Munsell Notations. Oxidized volcanic soils were usually red; e.g., soils Nos. 34, 116, and 196 in Table 1.

Soil moisture values show a range comparable to that of arable soils, although most of the values are quite low ($<1\%$) for the most arid areas, whether in hot or cold regions. The pH values are generally > 7.0, except in acidic volcanic areas or where there are possible influences from local accumulations of organic matter.

Electrical conductivity values, relative to kinds and concentrations of salts, vary considerably and are low in leached or nonsalty sandy areas, but quite high in areas where salts have accumulated as leachates or aeolian deposits. Sodium and calcium are the most predominate cations, and chlorides and sulfates are the most predominate anions. Phosphate and nitrate are low in nearly all of the soils. Nitrate is high only in some samples from cold deserts (No. 500) or the Chilean Atacama Desert (No. 288) where precipitation, leaching, and biotic activity are practically nil. However, nitrate formation may have been due to former microbial activity.

Organic carbon and nitrogen values are not appreciable in most desert soils, except in the vicinity of higher plants or in favorable microenvironments, where mosses, lichens, and algae can accumulate; e.g., polar soils Nos. 6 and 7 (Refs. 11 and 12). As might be expected, the cation exchange capacity is generally low in most desert soils because of the low contents of clays and organic matter.

The results of microbiological determinations are shown in Table 2. There is a wide range in abundances of microflora, with an extreme range of zero (undetectable) to approximately 10^8/g of soil as shown by cultural methods. If there are any microorganisms present at all, these are usually aerobic or microaerophilic, heterotrophic bacteria. Results with additional culture media (e.g., indigenous soil extracts, salt-organic enrichment, Van Delden's sulfate reduction agar, Burk's nitrogen-fixation agar, and actinomycete agar with glycerol) give similar abundances in some cases.

In dry, hot desert soils, the most frequently encountered bacteria, in order of decreasing abundance, were *Bacillus* spp., soil diphtheroids, *Pseudomonas* spp. and *Micrococcus* spp. (Ref. 27).[2] The bacilli were usually *B. subtilis*, *B. megatherium*, or *B cereus*. In cold deserts, soil diphtheroids, *Mycococcus* spp., and *Micrococcus* spp. were the most frequently observed microorganisms. *Mycococcus* spp. were more common in cold deserts and the Chilean Atacama Desert than in other desert areas (Ref. 27). *Mycococcus* spp. have also been isolated from high mountain soils (Ref. 28). The spore-forming bacteria, as well as spore-forming algae, were seldom present in soils of the Antarctic dry valleys. Actinomycetes (streptomycetes) were present in all desert areas, but not in all samples collected from a particular area. The most frequently encountered actinomycetes were *Streptomyces* spp. (Ref. 27). In studies of Sahara Desert soils, *Bacillus* spp. were found in nearly all of the soils examined, and *Actinomyces* (*Streptomyces*) spp. were present in 80% of the samples (Ref. 29).

Next in abundance to the aerobic and microaerophilic bacteria and streptomycetes, the algae were most prominent. For every sample that contained algae, the bacteria were also present, but the opposite condition was not found in any sample. The algae were not as evenly distributed in the soil as the bacteria, either with depth of soil or within a given area and volume of soil. The algae were usually at the soil surface or just below the surface, and were present in approximately three out of every four samples examined. It was not always possible to detect the algae in uncultured soil samples by direct microscopic observation if their abundance was < 100/g of soil. Depending upon such factors as the past history of freezing and thawing, wetting and drying, and especially the last period of available moisture, the algae, as well as some of the other microorganisms, needed a longer incubation period before growth was observed. For this reason, it was sometimes necessary to lengthen incubation up to six months before terminating the incubation.

[2]The soil diphtheroids include a group of pleomorphic cocci-rods that have been placed by various workers in the following species: *Mycococcus*, *Mycobacterium*, *Arthrobacter*, *Corynebacterium*, *Protoactinomyces*, and *Nocardia*.

Table 1. Physical and chemical properties of surface desert soils

Desert region and location	Texture	Color and Munsell Notation, air dry soil	*In situ* moisture, wt %	pH, saturated paste	Electrical conductivity (1:5 extract), 10^{-6} mhos/cm^2 at 25°C	Ions, ppm in 1:5 (soil:H_2O extract)									Organic C, %	Organic N, %	Cation exchange capacity meq/100g	JPL soil No. and remarks
						Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	$SO_4^=$	HCO_3^-	NO_3^-	$PO_4^{\equiv}$				
1. Cold desert, McKelvey Valley, Antarctica	Loamy sand	Reddish brown, 10 YR 6/2	1.4	7.9	4950	650	5	190	71	665	510	24	780	0.1	0.09	0.007	8.0	500
2. Cold desert, Victoria Valley, Antarctica	Sand	Pale yellow, 5 Y 7/3	0.24	8.9	88	8	1	8	1	5	8	24	2	0.2	0.02	0.002	4.0	537
3. Cold desert, Asgard Range, Antarctica	Sandy loam	Greyish brown, 2.5 Y 5/2	5.0	7.4	8400	1150	245	37	100	2340	450	61	130	0.8	0.04	0.007	11.0	664
4. Cold desert, Wheeler Valley, Antarctica	Sand	Light olive brown, 2.5 Y 5/4	8.9	8.1	380	21	8	20	5	41	15	30	7	0.2	0.17	0.024	2.5	615
5. Polar desert, Inglefield Land, Greenland	Gravelly sand	Brown, 7.5 YR 5/4	—	8.8	—	2.3	11.7	15	3.7	—	—	—	—	—	0.42 (organic matter)	—	0.9	Site 2 A horizon; Ref. 11
6. Polar desert, Prince Patrick Island, N.W.T. Canada	Sand	Yellowish brown, 10 YR 5/6	—	4.4	79000 (1:2 extract)	—	—	—	—	—	—	—	—	—	1.70 (organic matter)	—	—	Profile 1, loose and dry sand; Ref. 12
7. Polar desert, Jørgen Brønlunds Fjord, PearyLand, Greenland	—	—	—	7.5	—	—	—	—	—	—	—	—	0[a]	—	35.6 (humus)	1.05 (total)	—	Jensen No. 4 somewhat dry ground; stonefield; Ref. 9
8. High mts., White Mt. Summit, Inyo Nat. Forest, Calif.	Stony sandy loam	Pale brown, 10 YR 6/3	9.2	6.3	16	5	3	9	1.1	4	11	15	28	1.1	0.55	0.070	10.0	14; stony peak; elevation 4350 m
9. High mts., Mt. Aucanquilcha, near Amincha, Chile	Angular cobbly sand	White, 2.5 Y 8/2	1.2	2.6	17600	35	10	350	45	105	2700	0	0	2.0	0.06	0.006	0.0	256; extinct volcano; elevation 7800 m
10. Hot desert, Atacama near Prosperidad, Chile	Sandy loam	Pinkish grey, 7.5 YR 7/2	0.90	8.2	39200	1450	155	4250	75	530	10000	0	2500	1.0	0.04	0.003	0.5	288

[a]Weak positive.

Table 1 (contd)

Desert region and location	Texture	Color and Munsell Notation, air dry soil	*In situ* moisture, wt %	pH, saturated paste	Electrical conductivity (1:5 extract), 10^{-6} mhos/cm^2 at 25°C	Ions, ppm in 1:5 (soil:H_2O extract)									Organic C, %	Organic N, %	Cation exchange capacity meq/100g	JPL soil No. and remarks
						Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	$SO_4^=$	HCO_3^-	NO_3^-	$PO_4^{\equiv}$				
11. Hot desert, eastern Sahara near Abu Simbel, Egypt, U.A.R.	Loamy sand	Light brown, 7.5 YR 6/4	0.78	8.0	1230	55	40	40	15	5	10	43	3	0.5	0.17	0.006	7.0	295
12. Hot desert, Negev, Dead Sea, near Chamai Zohar, Israel	Sandy loam	Light yellowish brown, 10 YR 6/4	2.2	7.6	2750	270	50	150	54	940	12	24	1	0.5	1.45	0.012	14.0	220
13. Hot desert, Patagonian, west of San Julian, Argentina	Sandy loam	Light brownish grey, 10 YR 6/2	—	7.4	153	11	18	100	1	40	225	18	20	0.2	0.44	0.052	6.0	237; Dr. L. Halperin No. 605/35, Instituto de Suelos y Agrotechnica, Buenos Aires, Argentina
14. Hot desert, Great Basin Oregon Desert, near Brothers, Ore.	Loamy sand	Light brownish grey, 10 YR 6/2	35.5	6.7	151	10	16	9	7	30	300	24	10	1.0	0.58	0.056	10.0	154; snow cover on soil at time of collection
15. Hot desert, Wyoming Red Desert, near Thermopolis, Wyo.	Silt loam	Yellow, 2.5 Y 7/6	3.5	7.7	1740	5	8	440	72	4	940	30	2	0.08	0.58	0.023	3.5	311
16. Hot desert, Mohave Desert, Eureka Valley, Calif.	Sandy loam	Grey, 2.5 Y N5/	2.4	8.1	3100	270	10	375	11	2	1500	0	0	0.0	0.70	0.190	2.0	47
17. Hot desert, Sonoran Arizona Upland Desert, near Mammoth, Ariz.	Loamy sand	Brown, 10 YR 5/3	1.7	7.6	143	1	15	100	45	2	30	31	1	3.5	0.46	0.045	6.5	99
18. Hot desert, Sonoran Colorado Desert, near Thermal, Calif.	Clay	Pink, 5 YR 7/4	3.3	7.6	3700	550	47	125	16	586	1150	43	14	0.1	0.27	0.026	16.5	6-1 (No. 6); No. 6-1 collected 1 year after No. 6 at same site

Table 1 (contd)

Desert region and location	Texture	Color and Munsell Notation, air dry soil	*In situ* moisture, wt %	pH, saturated paste	Electrical conductivity (1:5 extract), 10^{-6} mhos/cm^2 at 25°C	Ions, ppm in 1:5 (soil:H_2O extract)									Organic C, %	Organic N, %	Cation exchange capacity meq/100g	JPL soil No. and remarks
						Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	$SO_4^=$	HCO_3^-	NO_3^-	$PO_4^{\equiv}$				
19. Hot desert, Sonoran Yuma Desert, Algodones Dunes, near W. Cactus, Calif.	Sand	Light yellowish brown, 10 YR 6/4	0.16	8.3	41	2	2	2.5	0.6	2	0	21	1	0.4	0.04	0.002	0.0	88
20. Hot desert, Sonoran Viscaino Magdalena Desert, near Punta Prieta, Baja Calif., Mexico	Loamy sand	Pale brown, 10 YR 6/3	0.70	8.2	1850	8	21	29	8	40	300	60	1	1.5	0.29	0.021	5.0	188
21. Hot desert, Sonoran Gulf Coast Desert, near Navajoa, Mexico	Loamy sand	Grey, 5 YR 5/1	4.3	8.0	81	1.5	1	3.4	1.8	4	10	24	3	0.5	0.84	0.074	18.5	250
22. Hot desert, Chihuahuan Desert, near Las Cruces, N. Mex.	Sandy loam	Brown, 10 YR 5/3	3.1	8.0	115	2	10	3.5	1	3.5	10	51	0	1.05	0.39	6.0	0.023	395
23. Volcanic desert (within Mohave Desert) near Little Lake, Calif.	Coarse sand	Weak red, 10 R 4/3	0.05	9.1	1550	17	5	12	5	35	300	6	0	2.0	0.03	0.005	1.0	196
24. Volcanic desert, Valley of 10,000 Smokes, Katmai Nat. Monument, Alas.	Loam	Pink, 5 YR 7/3	20.0	4.5	16	7.8	<5	<40	<2	13	<150	0	1	<0.5	0.07	0.004	3.0	116
25. Volcanic desert, Kau Desert, Hawaii Nat. Parks, Hawaii	Sandy loam	Dusky red, 2.5 YR 3/2	6.3	5.2	145	50	34	6	5	20	150	0	0	0.5	0.06	0.005	3.5	34
26. Volcanic desert, Surtsey, Iceland	Sand	Olive grey, 5 Y 4/2	0.04	6.6	730	52	60	220	87	—	68	—	0	1.0	0.0	0.0003	—	Ames No. SC-A, collected by Dr. R. Young, Ames Research Lab., Moffett Field, Calif. (analyses provided by Ames)

Table 2. Microbiological determinations of surface desert soils[a]

Desert region and location	Aerobic bacteria and actinomycetes	Microaerophiles (positives at highest dilution)	Anaerobic bacteria	Fungi		Algae (positives at highest dilution)	JPL soil No. and remarks
				Molds	Yeasts		
1. Cold desert, McKelvey Valley, Antarctica	25	100	0	0	0	0	500
2. Cold desert, Victoria Valley, Antarctica	8×10^3	10^4	0	0	0	10^3	537
3. Cold desert, Asgard Range, Antarctica	0	0	0	0	0	0	664
4. Cold desert, Wheeler Valley, Antarctica	10^5	10^6	0	200	0	6×10^6	615
5. Polar desert, Franz Joseph Land, Hooker Island	2.4×10^6	—	—	11×10^3	—	—	Gravel and marshy soil (mean values); Ref. 10
6. Polar desert, New Siberian Islands, (Kotelnyi Island)	2.9×10^6	—	—	8.3×10^3	—	—	Peat moss turf and bare ground (mean values); Ref. 10
7. Polar desert, Jørgen Brønlunds Fjord, Peary-Land, Greenland	14.1×10^6	Present	10	Present	Present	Present	Jensen No. 4; somewhat dry ground; stonefield; Ref. 9
8. High mts., White Mt. Summit, Inyo Nat. Forest, Calif.	2×10^6	10^6	15×10^4	3.2×10^3	—	10^3	14-1
9. High mts., Mt. Aucanquilcha near Amincha, Chile	600	10^6	0	0	—	0	256
10. Hot desert, Atacama, near Prosperidad, Chile	<10	100	0	0	—	0	288
11. Hot desert, eastern Sahara, near Abu Simbel, Egypt, U.A.R.	160×10^3	10^3	5	15	—	0	295
12. Hot desert, Negev, Dead Sea, near Chamai Zohar, Israel	132×10^5	10^4	0	260	—	10^3	220
13. Hot desert, Patagonian, west of San Julian, Argentina	71×10^4	10^6	53×10^3	370	—	10	237; Dr. L. Halperin No. 605/35, Instituto de Suelos y Agrotechnica, Buenos Aires, Argentina
14. Hot desert, Great Basin Oregon Desert, near Brothers, Ore.	72×10^5	10^7	16×10^4	0	—	10^3	154
15. Hot desert, Wyoming Red Desert, near Thermopolis, Wyo.	11×10^5	10^7	520	23×10^4	—	10^5	311
16. Hot desert, Mohave Desert, Eureka Valley, Calif.	9×10^4	10^7	0	34×10^4	—	100	47
17. Hot desert, Sonoran, Arizona Upland Desert, near Mammoth, Ariz.	15.3×10^5	10^8	8×10^5	170	—	10^3	99
18. Hot desert, Sonoran, Colorado Desert, near Thermal, Calif.	87×10^3	10^4	1.5×10^3	400	—	10^3	6-1
19. Hot desert, Sonoran, Yuma Desert, Algodones Dunes, near W. Cactus, Calif.	19.5×10^3	10^5	525	10	—	0	88

[a]Microorganisms per gram of soil.

Table 2 (contd)

Desert region and location	Aerobic bacteria and actinomycetes	Microaerophiles (positives at highest dilution)	Anaerobic bacteria	Fungi		Algae (positives at highest dilution)	JPL soil No. and remarks
				Molds	Yeasts		
20. Hot desert, Sonoran, Viscaino-Magdalena Desert, near Punta Prieta, Baja, Calif., Mexico	25×10^5	10^7	0	4.9×10^3	—	10^4	188
21. Hot desert, Sonoran Gulf Coast Desert, near Navajoa, Mexico	17.2×10^5	10^7	1.8×10^3	1.3×10^3	—	10^6	250
22. Hot desert, Chihuahuan Desert, near Las Cruces, N. Mex.	17×10^4	10^3	11×10^3	1.3×10^3	—	100	395
23. Volcanic Desert (in Mohave Desert) near Little Lake, Calif.	75×10^3	10^8	0	30	—	0	196
24. Volcanic Desert, Valley of 10,000 Smokes, Katmai, Nat. Monument, Alas.	10	10	0	10	0	10^4	116
25. Volcanic desert, Kau Desert, Hawaii Nat. Parks, Hawaii	13.2×10^3	10^6	50	3.3×10^3	—	10^5	34
26. Volcanic Desert, Surtsey, Iceland	0	0	0	0	0	0	Ames No. SC-A, collected by Dr. R. Young, Ames Research Lab, Moffett Field, Calif. (JPL analysis)
Media for JPL soils	Trypticase soy agar	Fluid thioglycollate	Trypticase soy agar in CO_2	Rose bengal agar	DiMenna yeast agar	Pochon's medium or Thornton's medium without organics	All incubations at "room temperature"

A discussion of the world-wide distribution of desert algae has been given previously (Ref. 30). The filamentous blue-green algae and coccoid green algae occupy the most xeric habitats. Coccoid blue-green algae and other algae (e.g., filamentous greens and diatoms) become more evident as the duration of available moisture increases. The most predominant blue-green algae are filamentous non-sporeforming oscillatorioid forms of *Schizothrix*, *Microcoleus*, and *Oscillatoria* spp. One species, *Schizothrix calcicola*, was present as a single population when no other algal species could be detected (Fig. 7). It is apparent after extensive study of specimens collected from a wide variety of habitats that this species is probably the most widely distributed algal species on this planet (Ref. 31). Coccoid green algae most closely resembled species popularly identified as *Protococcus grevillei* or *Chlorococcum humicola* (Ref. 30).

Protozoa were sometimes observed in the algal cultures, but they were more transient in their appearance than the algae. When present, they were less abundant than the algae; however, they may be present more frequently than is realized. Flagellated or amoeboid forms were most commonly observed; e.g., *Rhynchomonas* and *Amoeba* spp.

The fungi were represented primarily by ascomycetous molds. Yeasts were infrequently found in hot desert soils.

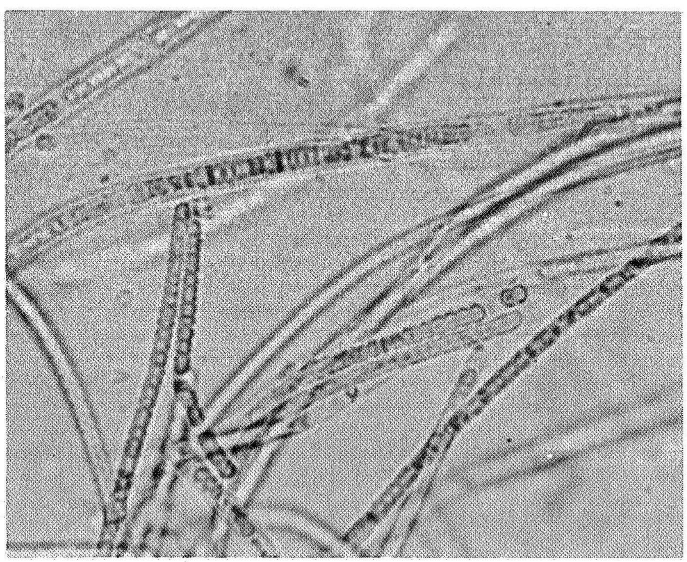

Fig. 7. Photomicrograph (× 1,250) of *Schizothrix calcicola*, the most abundant and most frequently occurring alga in desert soils (JPL soil No. 6)

Cryptococcus and *Rhodotorula* spp. were among the most frequent isolants from our Antarctic soils.[3] They occurred throughout the soil profile but were most influenced by the presence of moist organic matter in the soil. If they were present in the absence of algae, then they were not present in large numbers relative to the bacteria. *Penicillium* spp. and *Aspergillus* spp. followed by members of the *Moniliaceae* were the most frequently encountered fungi in our desert soil samples (Ref. 32). *Penicillium* and *Aspergillus* spp. were also the most frequently encountered fungi in Sahara Desert soils, occurring in approximately 80% of the samples examined (Ref. 29).

The anaerobic bacteria were not found in any of the samples unless other microorganisms, especially the aerobic or microaerophilic bacteria, were also present. If the anaerobic bacteria were present, their abundance did not exceed that of the other bacteria. Whenever they were found, the molds were usually also detected. No anaerobes were present in uncontaminated surface soils from the driest desert regions, and only rarely were they found in subsurface samples collected at the same site. Accumulations of moist organic matter greatly enhanced the possibility of finding anaerobes.

Other microorganisms that were rarely encountered in desert soils included strict chemoautotrophic, photoautotrophic, and halophilic bacteria and coliforms. These bacteria can be found in favorable microenvironments where the moisture supply is adequate for an extended time period and other factors, such as organics, can meet specialized nutritional requirements. Although photosynthetic halophiles have been isolated from salt lakes in hot deserts (Ref. 33), they have not been found in cold desert lakes or soils (Refs. 34–36). Viable coliforms, as determined by culturing in lactose broth and desoxycholate agar, were seldom found unless fecal contamination was frequent, fresh, and kept moist.

Microenvironments are extremely important for determining the abundance, distribution, and kinds of microorganisms in terrestrial desert soils. The importance of microenvironments has also been indicated for possible life in extraterrestrial environments (Refs. 1, 24, and 37). Soil moisture is the most crucial factor, and if present, then it must be of sufficient quality as well as available

[3]Personal communication from Dr. M. diMenna, Ruakura Agricultural Research Centre, Ruakura Soil Research Station, Department of Agriculture, Hamilton, New Zealand, 1968.

quantity for a sufficient time period to be utilized by microorganisms (Ref. 38).

The most important ecological factors are not readily apparent in desert soil ecosystems, especially if macroplants and animals or their remains are present, or if the ecosystem has been disturbed by man. In the relatively undisturbed, cold, barren, dry valley deserts of Antarctica, important environmental factors have been studied in detail relevant to desert soil microbial ecology (Ref. 39). These ecological factors, both favorable and unfavorable, are listed in Table 3. As a result of our observations and measurements of these environmental factors, an ecological sequence of microorganisms and cryptogams has become apparent (Fig. 8). Further studies of all desert areas may help to substantiate this sequence. It will also provide valuable information before looking for microbial life forms in other terrestrial desert areas or in harsh extraterrestrial environments. If no life can be detected, then the measurement of physical parameters becomes more important, and if only physical parameters are measured, then it can be postulated as to how many of what kinds of biota can exist under a similar given set of ecological or environmental conditions.

Table 3. Ecological factors determining distribution of life in Antarctic dry valleys

Favorable	Unfavorable
N-S orientation	E-W orientation
Northern exposure	Southern exposure
Gentle, north-facing slopes	Flat or south-facing slopes
High solar radiation	Low solar radiation
Microclimate above freezing	Microclimate below freezing
Absence of wind	High winds
Northerly winds	Southerly winds
High humidities	Low humidities
Slow or impeded drainage	Rapid drainage
Lengthy duration of available H_2O (presence of glaciers, lakes, streams, snow and ice fields)	Short duration of available H_2O (absence of glaciers, lakes, streams, snow and ice fields)
Translucent pebbles	Opaque pebbles
Non-salty soils, balanced ionic composition	Salty soils, unbalanced ionic composition
Approximately neutral pH	High (or low) pH
Organic contamination (skuas, seals, etc.)	No organic contamination (no large increments of organic matter)

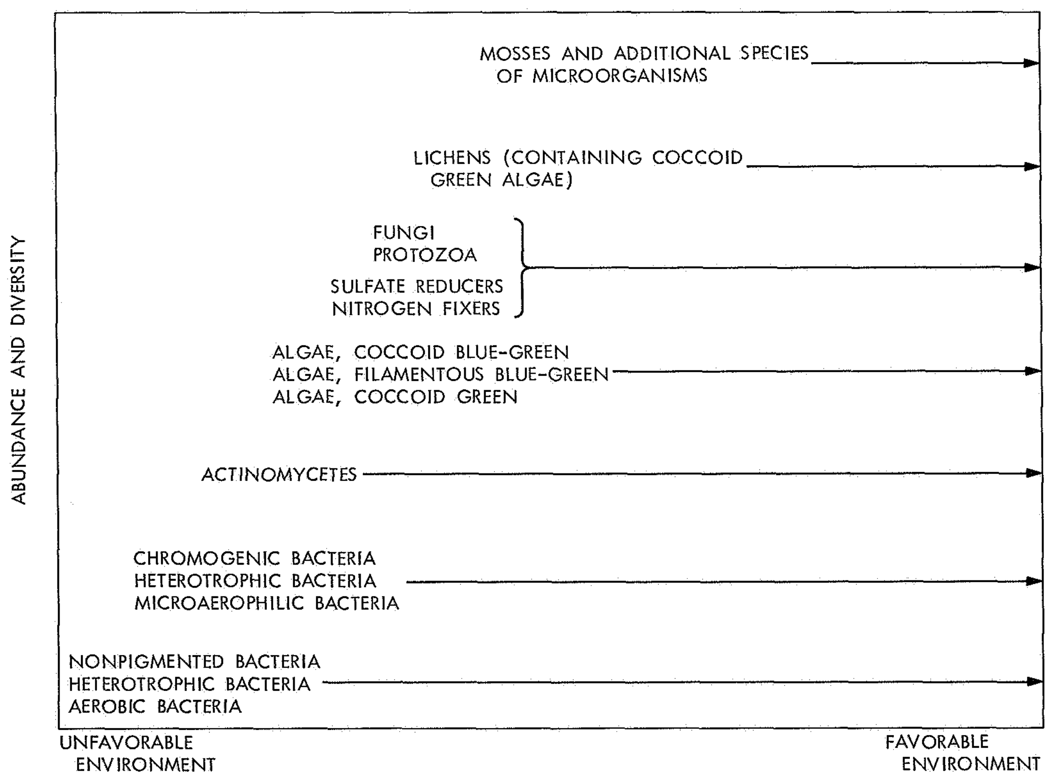

Fig. 8. Variability of population density and diversity with variability of ecological factors in Antarctic dry valleys

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